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An Energy Based Approach to Determine the Plastic Li[illegible]t of Fine-Grained Soil using Modified Cone Penetro[illegible]eter

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Abstract

The traditional thread-rolling method given by Casagrande for determ[illegible] plastic limit of [illegible]-grained soil is largely dependent on operator's efficiency and may often give inconsistent [illegible]nreliable results. Hence there is a need to device a new method that can give consistent and reliable results almost [illegible]y time with[illegible] much dependency on operator's efficiency. This paper describes an innovative energy-based approa[illegible]t yields A[illegible]berg plastic limit values of fine-grained soils utilizing a 0.727 kg cone which is made to fall freely th[illegible] 200 [illegible] before coming in contact with the surface of the test specimen, with the plastic strength li[illegible]ned for a cone penetration depth of 20 mm and compares the values with those obtained by traditional Casagrand[illegible]astic [illegible]st. The data analysis proves that the result gives satisfactory correlation with the rolling thread test.

Keywords: *Plastic limit; liquid limit; [illegible]ne pe[illegible] [illegible] soils;*

1. Introduction

The soil [illegible]n be remou[illegible] in the presence of some moisture without crumbling, when clay minerals are presented in fi[illegible]ained soil. Thi[illegible]esive nature caused by the adsorbed water surrounding the clay particles. In the early [illegible]s, a S[illegible]edish scienti[illegible] named Atterberg developed a method to describe the consistency of fine-grained s[illegible] with v[illegible]ng moisture contents. Soil behaves more like a solid at very low moisture content and may be flow[illegible]quid wh[illegible] the moisture content is very high. Therefore, the soil behaviour is depending on the [illegible]ture c[illegible]t level[illegible]nce, on an arbitrary basis, depending on the moisture content, the behaviour of soil [illegible]ded in[illegible]sic states. They are solid, semisolid, plastic and liquid.

[illegible]ysical properties of fine grained soils can be defined by its consistency limits. Index properties [illegible] the liq[illegible] limit (LL, W_L) and plastic limit (PL, W_P) are widely used to evaluate certain geotechnical pa[illegible]ters of fine-grained soils. The method for determining the W_L is a mechanical process, and the possibility of er[illegible]ccurring during measurement is not significant.

While geotechnical literature has noted the increasing popularity of the fall-cone LL method in the international community of practice, numerous studies have also looked at fall cone methods for determining PL

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(Wood and Wroth 1978; Campbell and 1976; Sharma and Bora 2003; Feng 2004;). The almost-universal method for determining PL, the rolled thread test, has remained relatively unchanged since Terzaghi (1927) modified Atterberg's procedure. Rolled-thread test results are often inconsistent and rely heavily on operator judgment.

Researchers have identified the main issues or primary problems relating to the standard evaluation of W_P and, in an attempt to improve accuracy, have developed several revised methods. Many of them are based on the falling cone approach used for W_L tests to come up with a device that is more accurate and generally repeatable when performed under similar conditions. The value of the plasticity index I_P can be computed f[illegible] liquid and plastic limits ($I_P = W_L - W_P$). I_P can be used in soil classification and in correlations wi[illegible] geotechnical soil properties, for example with soil strength.

Therefore several studies have been conducted using fall cone test to determine [illegible]e W_P [illegible]h as Karlsson (1961), Wood and Worth (1978), Feng (2004), Rashid (2005), Prakash and Shridh[illegible] (2006), [illegible]ll (2008) and Sivakumar et al. (2009) to introduce an alternative method for the determinatio[illegible] plastic limit.

1.1 *Basis to the proposed approach*

Wroth and Wood (1978), Wood (1990), Stone and Phan (1995) and [illegible]ma and Bo[illegible] 200[illegible] among others, have reported that for many inorganic fine-grained soils of low and i[illegible]iate plasticit[illegible] saturated undrained strengths cu(LL) and cu(PL) at Casagrande W_L and P_L are [illegible]pprox[illegible]ely 1.7 and 170 kPa respectively. On this basis, the strength variation over the plastic range (cu(PL)/c[illegible]L)) is, 100 for many inorganic fine-grained soils. This has been demonstrated experi[illegible] by Sharma a[illegible]ora (2003) for 55 different soils. However, the measured strength variation ove[illegible]e plastic range can potentially be 30–170 (Wood, 1990). Regression analysis of reported water content-[illegible]drained stre[illegible]h correlations for 14 mineral soils performed by O'Kelly (2013) indicated a strength variati[illegible]range of 4[illegible]28. However, in the authors' view, much of the variation in strength ratios may result from ina[illegible]te meas[illegible]ment of the strength mobilised at Casagrande LL. According to IS 2720-5 (BIS, 19[illegible]) the W_L co[illegible] the water content at which the free-falling 80 g–30º cone penetrates into the remou[illegible]ecimen to a depth (h) of 20 mm before coming to rest. At LL, the energy released by the falling cone [illegible]C@LL)[illegible] difference in potential energy of the cone before and after penetration, which is given by

$$E_{(C@LL)} = m_{LL}\, g\, h \tag{1}$$

where m_{LL} is the cone m[illegible]used in[illegible] fall-cone [illegible]L apparatus (i.e. 80 g in the present investigation) and g is the gravitational const[illegible]t.

With the $PL_{(100)}$ [illegible]ed in the sa[illegible]fashion as the Indian Standard fall-cone LL (i.e. water content for h = 20 mm), the cone [illegible]ired for the m[illegible]urement of the fall cone PL is 100 × mLL. Similarly, at $PL_{(100)}$, the energy released by [illegible]e hea[illegible]cone ($E_{(C@PL)}$) is the difference in the potential energy of the cone before and after penetration[illegible]

$$E_{(C@PL)} = 10[illegible]\, m_{LL}\, g [illegible] \tag{2}$$

Fo[illegible] cones i[illegible]erm of cone surface roughness and apex angle, the deformed shapes of the soil afte[illegible]tratio[illegible]LL an[illegible]L are similar. Under these conditions, the energy dissipated in the soil at $PL_{(100)}$ is 1[illegible] ti[illegible]hat fo[illegible]ce an 80 g cone is used in the Indian Standard fall-cone LL method, an 8 kg cone [illegible]ould th[illegible]efore be re[illegible]ired for measuring $PL_{(100)}$. Using this heavier cone in routine laboratory investigations is [illegible]ot pr[illegible] it may bring about health and safety issues during the testing. Instead, the required energy [illegible]0 times [illegible] for the fall-cone LL) can be extracted by

(a) B[illegible]reasing the cone mass to 8kg with a 30º cone angle and allowing the cone to be just in contact with the soil [illegible]fore allowing it to fall, or

(b) Increasing the falling distance of the cone while maintaining its mass of 80 g, or

(c) Increasing the cone mass and also incorporating a falling distance.

Increasing the cone mass to 8kg is not practical as it may bring about health and safety issues during the testing. If the cone mass of 80 g is to be maintained, the cone falling distance has to be 2.0 m, which is not a practical solution. Hence option (c) above is considered to be a more appropriate approach to achieve the required energy.

1.1.1 Equipment

The configuration adopted in the present study is shown in Figure 1. A cone of mass m is allowed to free fall from a stationary position through a clear distance of 200 mm before contacting the specimen surface. For the Indian Standard W_L method, the cone penetrates the soil by 20 mm at W_L. In the proposed W_P method after free falling through 200 mm, the $PL_{(100)}$ condition is defined by the cone penetrating into the soil by 20 mm before coming to rest; that is, the total falling distance is 220 mm. A simple calculation would show that the cone mass required for the proposed device is 0.727 kg; this means it generates 100 times the potential energy of the 80 g fall cone penetrating into soil prepared at LL. This is the premise on which the new apparatus was developed and evaluated.

Fig.1 Fabricated Cone Penetrometer with 0.727 kg cone weight.

1.2 Materials

Four natural soil samples, Shamsipur clay as sample A, Dayalpur clay as sample B, Samani clay as sample C and Ambala clay as sample D are tested for this study purpose. All the samples are taken around kurukshetra for easier transportation process. It would be expected that the plasticity index, PI of the soil range from 10 to 40 to achieve versatile results. The soil samples are pulverized to break lumps and then air dried before conducting laboratory tests to determine their respective index properties.

Laboratory tests including sieve analysis, W_L test using Casagrande apparatus, W_P test using Casagrande thread rolling method and specific gravity test using pycnometer are performed on each of the collected soil samples. The soil samples are then classified on the basis of their plasticity index. The results of the laboratory tests are tabulated in the table 1.

Table 1. Results of laboratory tests on various collected samples.

Sample	Properties	Result
A	Coarse grain size (%)	13.5
	Fine grain size (%)	86.5
	Liquid Limit, W_L (%)	29.4
	Plastic Limit, P_L (%)	16.2
	Plasticity Index, PI (%)	13.2
	Specific Gravity (G)	2.62
	Soil Classification (IS 1498:1970)	CL
B	Coarse grain size (%)	5.5
	Fine grain size (%)	94.5
	Liquid Limit, W_L (%)	48
	Plastic Limit, P_L (%)	29.5
	Plasticity Index, PI (%)	18[illegible]
	Specific Gravity (G)	[illegible]4
	Soil Classification (IS 1498:1970)	CI
C	Coarse grain size (%)	7.4
	Fine grain size (%)	92[illegible]
	Liquid Limit, W_L (%)	46.[illegible]
	Plastic Limit, P_L (%)	2[illegible]
	Plasticity Index, PI (%)	19
	Specific Gravity (G)	2.55
	Soil Classification (IS 1498:1970)	CI
D	Coarse grain size (%)	2.8
	Fine grain size (%)	97.2
	Liquid Limit, W_L (%)	54.2
	Plastic Limit, P_L (%)	33.5
	Plasticity Index, PI (%)	20.7
	Specific Gravity (G)	2.48
	Soil Classification (IS 1498:1970)	CH

2. Experimental programme

2.1 Validation of energy concept

Falling objects develop kinetic energy that increases with the falling distance in proportion to the square of velocity, assuming aerodynamic effects are negligible. The kinetic energy that the object has at a particular location/elevation is equivalent to the potential energy that the object has released over its falling distance. As part of the present investigation, an 8 kg–30° cone was allowed to penetrate into foam, with the cone [illegible] initially just contacting the foam surface. Out of 20 trials performed, the mean cone penetration depth was 11.04 mm, with standard deviation (SD) of 0.21 mm. Next, the 0.727 kg cone was allowed to free fall from a height of 200 mm above the foam surface and the resulting mean cone penetration depth was 11.17 mm, with SD of 0.14 mm, again for 20 trials. This observation generally confirms the energy conservation.

2.2 Specimen preparation

The samples for testing were prepared according to IS 2720: Part 5: 1985, dry preparation method, by sieving dry material through 425 µm. About 150 g of dry material was mixed with de-aired water in order to achieve water content somewhere around the W_P and this was achieved by thorough mixing the soil and storing the wet soil for 24 hrs.

The soil sample was carefully placed in layers and compacted into the standard cup of diameter 55 mm and 40 mm deep used for measuring W_L (IS 2720: Part 5: 1985). A collar was attached to the standard cup, to allow the production of a sample higher than the cup height, and the extra height was carefully trimmed off at the end of the sampling process.

2.3 Testing

The sample was ready for testing after it was carefully prepared and the extra height was carefully trimmed off and levelled. The cup was then placed on the cone penetrometer base plate and, making sure that the cone tip is resting on the rim of the cup. The initial reading is either adjusted to zero or noted down as is shown on the graduated scale, the cone was then retrieved back to its position 200 mm from the sample, Figure 2. The vertical clamp was then released allowing the cone to penetrate into the soil paste under its own weight and final reading was taken, Figure 3. The penetration of the cone after 5 seconds was noted to the nearest millimeter. If the difference in penetration lies between 14 to 28 mm, the test was repeated with suitable adjustments of the moisture either by addition of more water of exposure of the spread paste on a glass plate for the reduction in moisture content. The test was then repeated at least to have 4 sets of values of penetration in the range of 14 to 28 mm. A graph between moisture content and cone penetration was prepared and a best fit straight line was then drawn. The moisture content corresponding to the cone penetration of 20mm was taken as the W_P of the soil.

Fig.2 Retrieving the cone

Fig.3 Releasing the cone

3. Results and discussion

In order to ensure consistency, a strict procedure was adopted whereby the cone penetration depth for each water content value investigated was measured twice, with the average penetration reading used for further analysis. In almost every case, the difference in penetration readings from two repeat tests was below ± 0·25 mm, well within the ± 0·5 mm difference specified by the Indian Standard fall-cone LL method. Figure 4 shows the measured penetration depth (h) against water content relationship for Shamsipur soil sample, determined twice using the 0·727 kg–200 mm cone set-up. This study proposes that the fall-cone PL is defined as the water content corresponding to h = 20 mm, which from regression analysis corresponded to 29.80 ± 0·15% water content for this soil sample. These observations show that the procedure adopted is repeatable when performed under similar conditions.

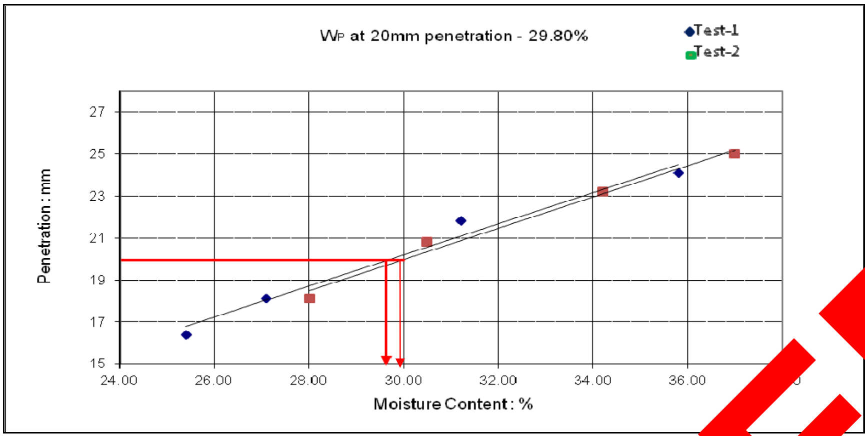

Fig 4. W_P of Shamsipur soil (Sample A) by modified falling Cone Test_0.727kg

Figure 5-7 shows the penetration depth against water content relationship for soil samples B, C and D using 0.727 kg cone set-up.

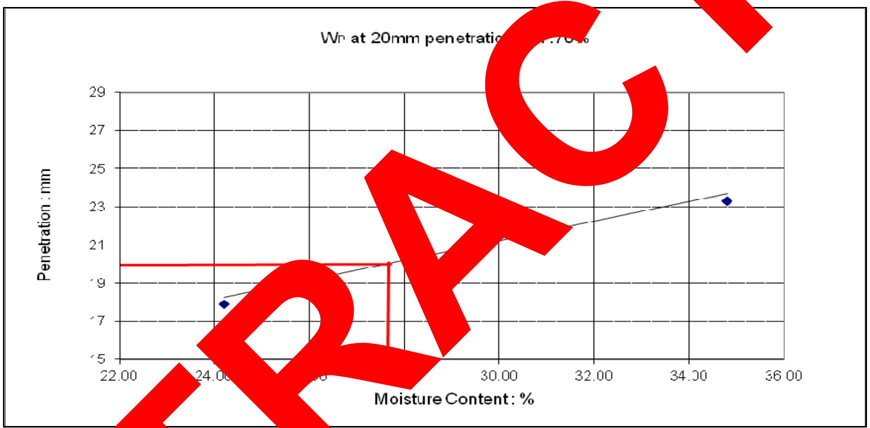

Fig 5. W_P of Dayalpur soil (Sample B) by modified falling Cone Test_0.727kg

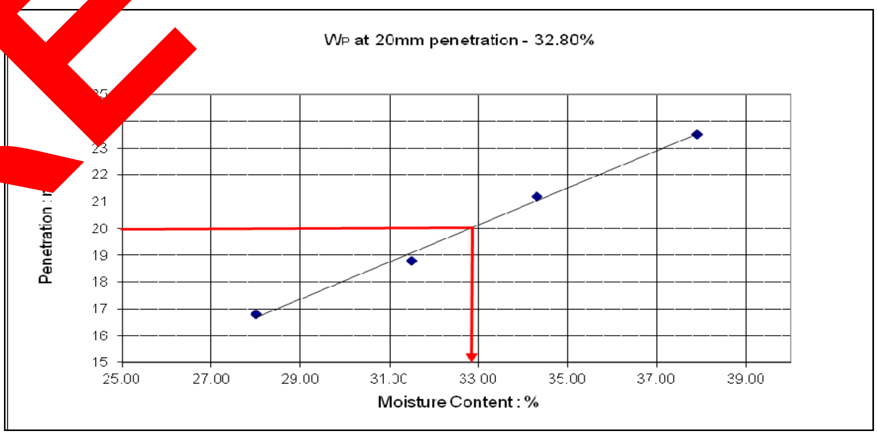

Fig 6. W_P of Samani soil (sample C) by modified falling Cone Test_0.727kg

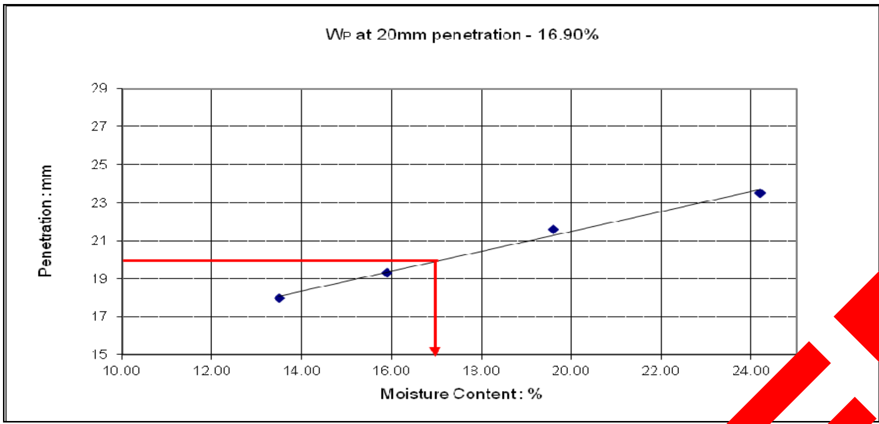

Fig 7. W_P of Ambala soil (Sample D) by modified falling Cone Test_0.[illegible]7kg

Table 2 list the W_P values determined for h = 20mm using 0.727 kg co[illegible]-up for the [illegible] di[illegible]ent soils. Also included in the table are the Casagrande W_P values determined by ro[illegible] the 3mm thr[illegible] of soil paste till it begins to disintegrate. When threads of the four soils were rolled o[illegible] at the [illegible]7 kg-200 mm W_P values, they began to disintegrate as their diameters approached to 3.0 m[illegible] Analysis of [illegible] data enable a direct comparison to be made between W_P determinations produced u[illegible] the current m[illegible]od and the proposed new method. This suggested that the 0.727 kg-200mm W_P agre[illegible] more favourably with the Casagrande W_P.

Table 2. Average PLs of soil samples by Casagrande metho[illegible] PLs by 0.727 [illegible] 200 mm cone setup.

Soil Sample	Avg Casagrand[illegible] by four tests: [illegible]	W_P (by 0.[illegible]e): %	[illegible]ference in W_P[a] %
Sample A	29.5	29.[illegible]	0.3
Sample B	27.2	[illegible]	0.5
Sample C	[illegible]	[illegible]2.8	0.7
Sample D	16.2	[illegible].9	0.7

[a] [illegible]iffere[illegible]een Casagrande W_P (average) and W_P (0.727 kg).

4. Conclusion

A new fall co[illegible]PL device [illegible]een developed using an energy-based criterion, with the required energy achieved by [illegible]ing a 0.727 kg–[illegible]one to free fall through 200 mm before penetrating into the soil specimen by 20 mm[illegible]reby d[illegible]ning the plastic strength limit. For all four mineral clays of intermediate to high plasticity tested, t[illegible]727 k[illegible]00 mm cone set-up produced W_P in good agreement with the measured Casagrande W_P. It is conclude[illegible]e new m[illegible]hod, in addition to being faster, gives plasticity test results comparable width and m[illegible]produ[illegible] than r[illegible]ts obtained using the Casagrande method.

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